Introducing Technological Pedagogical Content Knowledge

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We introduce the Technological Pedagogical Content Knowledge (TPACK) as a way of thinking about the knowledge teachers need to understand to integrate technology effectively in their classrooms. We argue that TPACK comprises knowledge of content, pedagogy, and technology, as well as understanding the complex interaction between these knowledge components. We argue that teachers who have this type of understanding are characterized by the creative, flexible, and adaptive ways in which they navigate the constraints, affordances, and interactions within TPACK framework. Examples of the types of knowledge in the framework, and teachers' using this knowledge are featured throughout the paper.

Integrating technology into teaching is not easy. Many researchers have accounts of it either not happening, happening too slowly, or happening with no effect on teachers' or students' learning (e.g., Cuban, 2001; Dynarski et al., 2007; Ross, Smith, Alberg, & Lowther, 2004). Why is this so hard?

One way of thinking about teaching with technology is to view it as a "wicked problem" (Rittel & Webber, 1973), in which the goal is to find the right combination of technologies, teaching approach, and instructional goals. Rittel and Webber make a distinction between wicked problems and "tame" problems, in that wicked problems are characterized by:

- Requirements that are incomplete, contradictory and changing
- Uniqueness, in that no two wicked problems are alike
- Occurring in complex and unique social contexts
- Solutions that are difficult to realize and recognize because of complex interdependencies and contexts
- Solutions that are not right or wrong, simply "better," "worse," "good enough," or "not good enough".
- Solutions that have no stopping rule, the best we can hope for is "satisficing," (Simon, 1969) – achieving a satisfactory solution, an outcome that, given the circumstances, is good enough.

Working with wicked problems is a process of utilizing expert knowledge to design solutions that honor the complexities of the situations and the contexts presented by learners and classrooms. For this reason, there is no definitive solution to a technology integration problem.

[1] Equal contribution of the authors. We rotate the order of authorship across our publications.

Each issue raised by technology integration presents an ever-evolving set of interlocking issues and constraints.

When we view teaching with technology as a wicked problem, it is clear that we require new ways of confronting this complexity. Recently, there has been considerable interest in using Technological Pedagogical Content Knowledge, or TPACK for short, as a framework for thinking about the complex problems posed by technology integration (Koehler & Mishra, 2008; Mishra & Koehler, 2006).

Introducing the TPACK Framework

We argue that at the heart of good teaching with technology are three core components: Content, Pedagogy & Technology. Equally important are the relationships between these three components. It is the interactions, between and among these components, playing out differently across diverse contexts, that account for the wide variations seen in educational technology integration. These three knowledge bases (Content, Pedagogy and Technology) form the core of the TPACK framework. We offer an overview of the framework below, though more detailed descriptions may be found in other published work (Koehler & Mishra, 2008, Koehler & Mishra, 2005a, 2005b; Mishra & Koehler, 2006).

In the TPACK framework, understanding arises from multiple interactions among content, pedagogical, and technological knowledge. It encompasses understanding the representations of concepts using technologies; pedagogical techniques that apply technologies in constructive ways to teach content in differentiated ways according to students' learning needs; knowledge of what makes concepts difficult or easy to learn and how technology can help redress conceptual challenges; knowledge of students' prior content-related understanding and epistemological assumptions; and knowledge of how technologies can be used to build on existing understanding to develop new epistemologies or strengthen old ones.

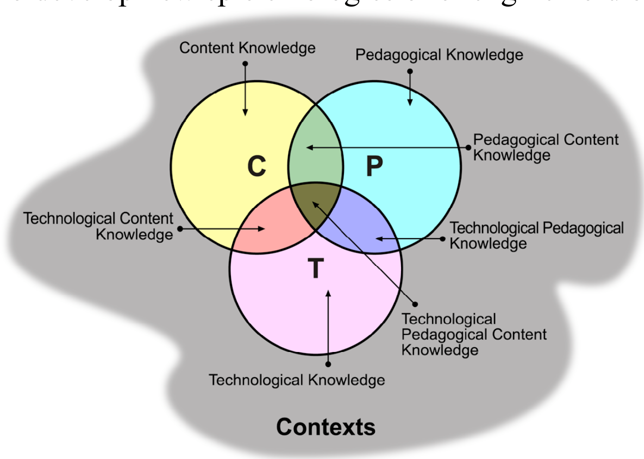


Figure 1. The TPCK framework and its knowledge components (Koehler & Mishra, 2008)

Technology Knowledge (T)

Technology knowledge (T or TK) is knowledge about standard technologies such as books and chalk and blackboard, as well as more advanced technologies such as the Internet and

digital video. This would involve the skills required to operate particular technologies. In the case of digital technologies this would include knowledge of operating systems and computer hardware, as well as the ability to use standard software tools including web-browsers, email programs, and word-processors. It includes basic knowledge about installing and upgrading hardware and software, maintaining data archives, and staying up to date about ever-changing technologies.

Beyond traditional notions of technical literacy, teachers should also understand information technology broadly enough to apply it productively at work and in their everyday lives, recognize when information technology can assist or impede the achievement of a goal, and to continually adapt to changes in information technology. This, obviously, requires a deeper, more essential understanding and mastery of information technology for information processing, communication, and problem solving than does the traditional definition of computer literacy. In this view, technology knowledge evolves over a lifetime, consisting of an open-ended interaction with technology.

Content Knowledge (C)

Content Knowledge (C or CK for short) is knowledge about the actual subject matter that is to be learned or taught. The content to be covered varies greatly by age level and subject-matter. Clearly, teachers must know and understand the subjects they teach, including: knowledge of central facts, concepts, theories and procedures within a given field; knowledge of explanatory frameworks that organize and connect ideas; and knowledge of the rules of evidence and proof (Shulman, 1986). Teachers must also understand the nature of knowledge and inquiry in different fields. For example, how is a proof in mathematics different from a historical explanation or a literary interpretation? Teachers who do not have these understandings can misrepresent those subjects to their students (Ball, & McDiarmid, 1990).

Discipline is often used to describe a set or "system of rules and regulations." This definition plays out differently in different contexts. In one sense of the word, discipline is "behavior in accord with rules of conduct; behavior and order maintained by training and control" and in the other sense of the term, discipline is a "a branch of instruction or learning" (Dictionary.com). Gardner has argued that disciplinary thinking is maybe the greatest invention of mankind (Gardner, 2000, 2005). He views the teaching of disciplines as the single most important and least-replaceable purpose of schooling. They are like "mental furniture" or what "we think in." Disciplines provide four things: knowledge (facts, concepts & relationships); methods (knowledge creation & validation processes); purposes (reasons why the discipline exists); and finally forms of representation (genres & symbol systems). Disciplines are powerful, because through a process of developing knowledge, methods, purpose, and representation they allow us to "see."

Each discipline, including typography, has special forms of knowledge. Consider the following example from typography (Figure 2). The discipline of typography is a field of knowledge comprising facts, concepts and relationships that often requires the development of specific, categorical sign and symbol systems. For example:

- Terms such as "stroke" and "baseline," for example, have very specific meanings.

- Relationships are complex, such as the one between a “counter” and a “stroke” which depends upon the purpose of the typeface (e.g., for use on a building sign vs. for use in a telephone directory).
- Categories such as “Blackletter” or “Sans-Serif” or “Grotesk” have specific characteristics.
- There are specific methods typographers have developed over time to create new fonts and processes of validating use.
- There are complex arguments about the purposes of typography—from communicative to aesthetic, from functional to expressive, and what its role is in society.

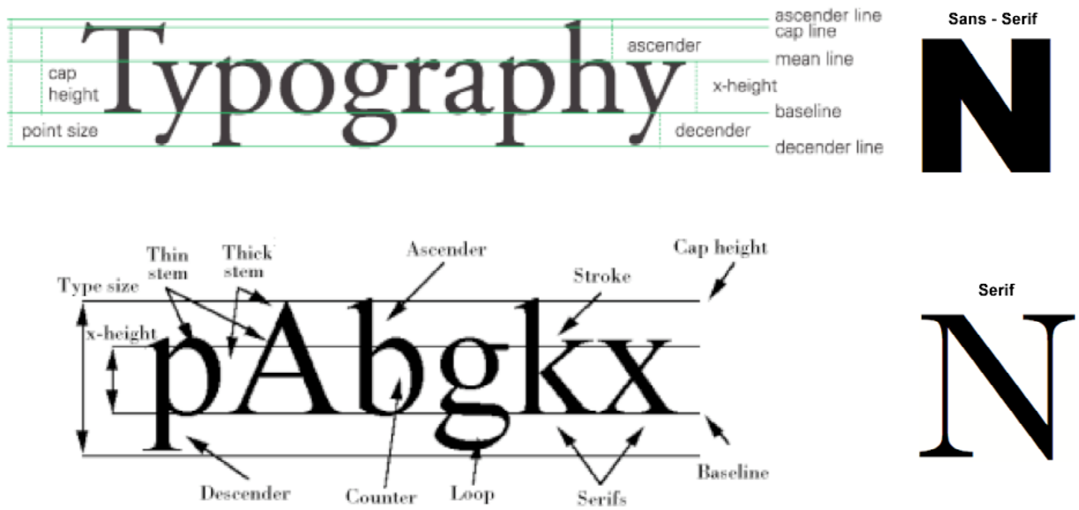


Figure 2: Example of Typography Discipline Knowledge

The specifics of this discipline are often difficult to describe because of the complex process of individual and group innovation and social construction within the field. The documentary *Helvetica*[2] describes how typefaces are created and validated in use through an active process of social construction, complete with great examples from the history of typography.

Within the discipline knowledge of typography, we can “see” subtleties not apparent at first glance. For example, though many people know the difference between serif and sans serif typefaces, not many people know that the serifed upper-case “N” has a little serif on the top left corner, but not a corresponding one at the bottom-right corner. This means that though the sans-serif “N” is symmetric to rotation, the serif version is not. Similarly not many people know that the letter “S” and the number “8” have a larger curve at the bottom than at the top.

Pedagogical Knowledge (P)

[2] To learn more about the film, visit http://www.helveticafilm.com/

Pedagogical Knowledge (PK or P for short) is deep knowledge about the processes and practices or methods of teaching and learning and how it encompasses (among other things) overall educational purposes, values and aims. This is a generic form of knowledge that is involved in all issues of student learning, classroom management, lesson plan development and implementation, and student evaluation. It includes knowledge about techniques or methods to be used in the classroom; the nature of the target audience; and strategies for evaluating student understanding. A teacher with deep pedagogical knowledge understands how students construct knowledge and acquire skills; develop habits of mind and positive dispositions towards learning. As such, pedagogical knowledge requires an understanding of cognitive, social and developmental theories of learning and how they apply to students in their classroom.

Pedagogical Content Knowledge (PC)

In the TPACK framework (Figure 1), there are the three components of knowledge represented by the three circles: Technology, Pedagogy, and Content. Equally important in this framework are the overlap between these components of knowledge. The first intersection in the framework is between pedagogy and content knowledge, or *Pedagogical Content Knowledge* (PCK or PC) (Shulman, 1986).

In considering the relationship between content and pedagogy, the key question is how disciplines differ from each other and whether disciplines can or should be taught through the same instructional strategies. If disciplines are the same, then mathematics can be taught using the same instructional strategies that we use to teach architecture or music. On the other hand, differences between the disciplines would argue for a need to teach them differently. Donald (2002) in her survey of how different disciplinary perspectives lead to different ways of thinking offers six fundamental, general thinking processes of expert and student thinking in different disciplines. These six processes describe what changes as students learn and think in specific disciplinary contexts:

- *Description* of context, conditions, facts, functions, assumptions, and goals
- *Selection* of relevant information and critical elements
- *Representation*: organizing, illustrating, and modifying elements and relations
- *Inference*: drawing conclusions, forming propositions
- *Synthesis*: composing wholes from parts, filling gaps, developing course of action
- *Verification*: confirming accuracy and results, judging validity, using feedback

Though these six processes apply to all disciplines, Donald (2002) shows that different disciplines emphasize certain processes and under-emphasize others. For example, *verification* in engineering would be pragmatic (does it work?), while in literature verification would be a search for interpretive coherence. One can make similar arguments for how these six processes play out differentially in other disciplines as well.

Donald argues that this has significant implications for instruction and offers a strong critique of content-neutral, simplistic one-size-fits-all educational strategies that would apply equally well to all disciplines. As Pintrich (2004) says in his review of Donald's book:

> Donald makes the case that instructional improvement must develop out of tasks, knowledge, and ways of thinking that characterize each discipline or field. This makes instructional improvement a much harder task, as it is not as simple as just picking up a few new instructional techniques at a faculty development workshop and then using them in class. Instructional improvement involves thinking clearly and deeply about the nature of the discipline and the desired knowledge and thinking processes and then designing instruction to facilitate and encourage the use of the knowledge and processes… There is no one "royal" road or a single developmental pathway that all instructors or all students must follow in the development of student thinking. (p. 480)

In this view, subject matter (disciplinary knowledge) is transformed for the purpose of teaching. It is this understanding of PCK that we advocate, one in which teachers interpret subject matter, find multiple ways to represent it, and adapt instructional materials to alternative conceptions and students' prior knowledge. What is salient in the content changes by the methods to be used, and the current understanding of students. This approach is consistent with Shulman's (1986) approach to PCK as knowledge of pedagogy that is applicable to teaching specific content, and using Gardner's (2000) language of the teaching of disciplines.

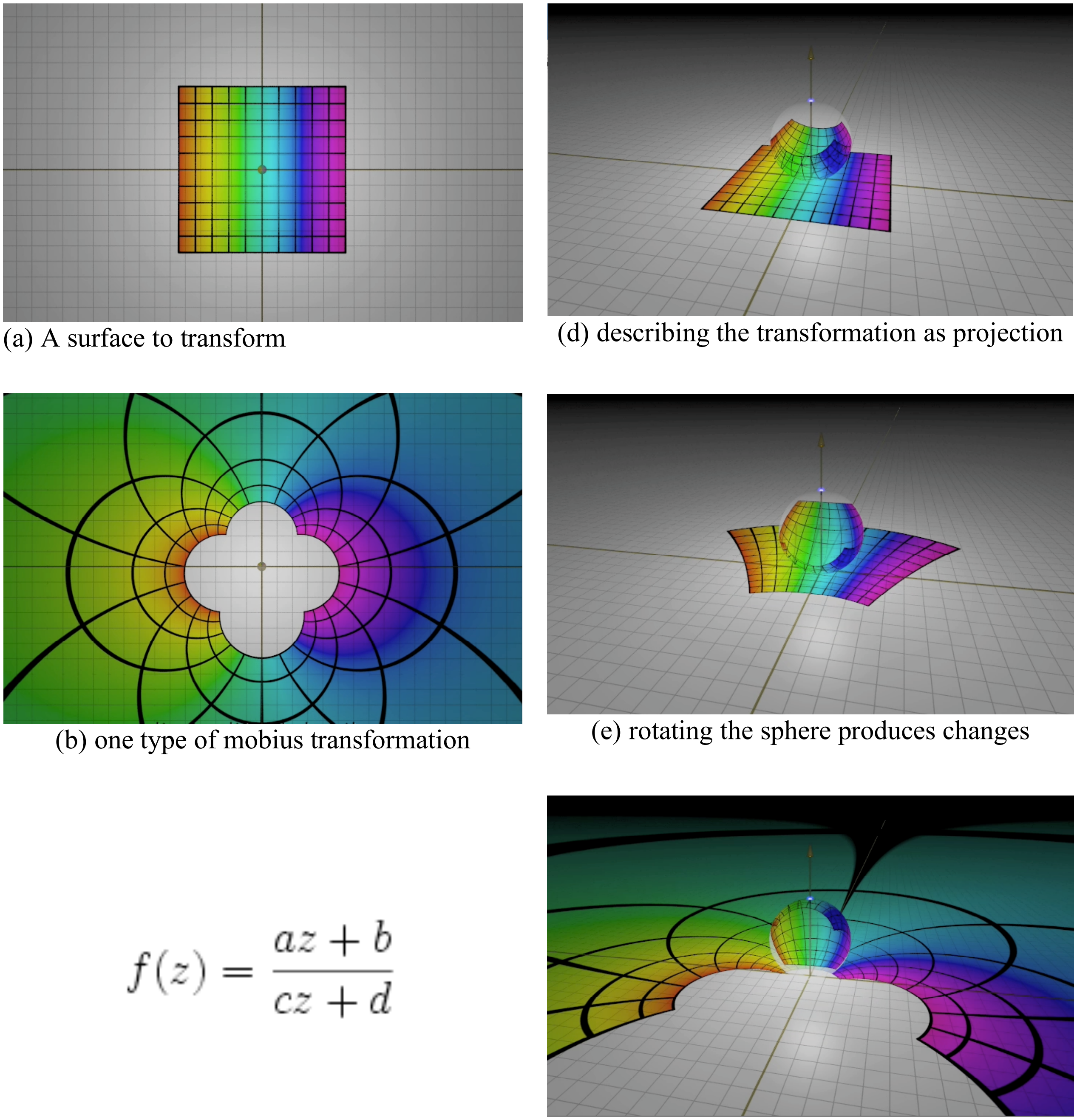
Technological Content Knowledge (TC)

Understanding the impact of technology on the practices and knowledge of a given discipline is critical if we are to develop appropriate technological tools for educational purposes. The choice of technologies affords and constrains the types of content ideas that can be taught. Likewise, certain content decisions can limit the types of technologies that can be used. Technology constrains the types of possible representations but conversely affords the construction of newer and more varied representations. Furthermore, technological tools can provide a greater degree of flexibility in navigating across these representations.

Accordingly, *Technological Content Knowledge* (TC or TCK), is an understanding of the manner in which technology and content influence and constrain one another. Teachers need to master more than the subject matter they teach, they must also have a deep understanding of the manner in which the subject matter (or the kinds of representations that can be constructed) can be changed by the application of technology. Teachers need to understand which specific technologies are best suited for addressing subject-matter learning in their domains and how the content dictates or perhaps even changes the technology—or vice versa.

Consider how the advent of computing technologies has changed the nature of disciplines such as mathematics, placing a greater role on simulation, representation, and graphical manipulation. Visualization technologies can change how some mathematical concepts are represented and understood. For example, let's consider mobius transformations – a way to transform or alter a 2d shape in some systematic way. Mobius transformations may be fairly easy to represent, as they all can be represented by the same equation: $f(z) = (az + b)/(cz + d)$.

However, many find it difficult to deeply understand how this symbolic function can produce the range of mobius transformations, including: translation (e.g., move to the left, move up, etc.), rotation (e.g., rotate 90 degrees), dilation or scale (e.g., making something bigger or smaller), reflection (flipping something horizontally or vertically), elliptical, parabolic, and inversion.



(a) A surface to transform

(d) describing the transformation as projection

(b) one type of mobius transformation

(e) rotating the sphere produces changes

$$f(z) = \frac{az + b}{cz + d}$$

(c) describing the transformation symbolically

(f) continued rotation creates the transformation

Figure 3: Describing mobius transformations as 3d projections onto a 2d-surface

Some of these transformations are relatively easy to understand (e.g., translation, rotation), but are difficult to connect to the symbolic formula. Others, like inversion, are both

difficult to understand and connect to the symbolic formula. Figure 3 helps depict a powerful example of how technology changes the types of representations available to represent content ideas (in this case, mobius transformations)[3]. Many find it difficult to understand how the inversion transformation could turn a standard grid (figure 3a) into a complex shape (figure 3b) using linear functions (figure 3c). A new representation, offered through a combination of 3d visualization and motion animation, makes this transformation much more understandable. Imagine a sphere is placed above the shape (figure 3d), so that the shape is projected from above through the sphere and onto the plane. Now, the inversion transformation is produced by slowly rotating the ball (figures 3e-3f). Accordingly, all of the mobius transformations may be understood as movements of this sphere. Here, the available technologies change the representation of the content. This example demonstrates just one of the many ways in which technology and content are related.

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Technological Pedagogical Knowledge

Technology and pedagogy mutually afford and constrain one another in any act of teaching. For example, consider how technology can afford new forms of pedagogy in the case of Moodle's (courseware) method of structuring online conversations. One option, called a "Q and A forum" requires students to post before they can see any other postings. Using this type of discussion, different pedagogies are afforded than are traditionally available. Of course, this can help instructors avoid the "me too" phenomena or the various forms of the "I agree" posting. The authors have used it to have students share their ideas of how a computer does a "magic" trick – in this activity it is important for students to think about (and post) their ideas, and not simply given the answer by reading other students' posts. But pedagogy could be advanced in any instance in which teachers want to ensure that students share their own unique perspectives, free from the influence of prior responses. For example, brainstorming sessions require ideas to flow freely, instead of following the first few (or most vocal) ideas. Some activities require conversation in which several different interpretations of an event or material are important.

Technological pedagogical knowledge (TP or TPK), then, is an understanding of how teaching and learning changes when particular technologies are used. This includes knowing the pedagogical affordances and constraints of a range of technological tools as they relate to disciplinarily and developmentally appropriate pedagogical designs and strategies. This requires getting a deeper understanding of the constraints and affordances of technologies and the disciplinary contexts within which they function.

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[3] A more complete treatment of this example and work, complete with video may be found at the website: http://www.ima.umn.edu/~arnold/moebius/ (Arnold & Rogness, 2007).

Technological Pedagogical Content Knowledge (TPACK)

Technological Pedagogical Content Knowledge (TPACK) is the intersection of all three bodies of knowledge. Understanding of this knowledge is above and beyond understanding technology, content, or pedagogy in isolation, but rather as an emergent form that understands how these forms of knowledge interact with each other. We argue that effective teaching with technology both requires TPACK, and is characterized by the competencies we include in our description of Technological Pedagogical Content Knowledge. These include an understanding of how to represent concepts with technologies, pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help students learn; knowledge of students' prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge and to develop new epistemologies or strengthen old ones.

Teaching as a Creative and Flexible Navigation of the TPACK Landscape

In our view, expert teachers consciously and unconsciously simultaneously integrate technology, pedagogy and content every time they teach. Every time they have to plan a lesson, they are confronted with a "wicked problem," in which there is a unique context that combines elements of content, pedagogy, and technology, and accordingly there is no single solution that will apply uniformly across teachers, courses, districts, or approaches. What these expert teachers do is flexibly navigate the space defined by the three elements of content, pedagogy, and technology and the complex interactions among these elements in specific contexts. That is, given a complex, dynamic problem, these teachers design curricular solutions as needed to fit their unique learners, goals and situation.

This type of teaching requires a deep, pragmatic, and nuanced understanding of teaching with technology. We understand that in some ways, the separation of teaching into content, pedagogy and technology is not necessarily straightforward, or even something that good teachers do. Instead, we believe when technology integration is working well, the system is in a state of "dynamic equilibrium" (Koehler & Mishra, 2008), such that "a change in any one of the factors has to be ‘‘compensated’’ by changes in the other two (Mishra & Koehler, 2006, p. 1029).

Teacher as Creative Designers of Curriculum

The TPACK framework suggests that the kinds of knowledge teachers need to develop can almost be seen as a new form of literacy - as a development of skills, competencies and knowledge in practice that goes beyond specific knowledge of particular disciplines, technologies and pedagogical techniques. This new form of literacy, however, emphasizes integration of these knowledge bases, going beyond standard definitions of literacy that often focus on instrumental competencies. We build on a definition of literacy suggested by Myers (1995) where he suggested that literacy is "the ability to consciously subvert signs." We argue that such an approach implies that knowledge required for teaching is "more than just the ability to use sign systems to communicate some conventional meaning, because… literacy should be

reserved for some state of agency in which one can control, even manipulate, how signs are used." (Myers, p. 582).

There are many reasons we support this new approach towards teacher knowledge. First, this definition emphasizes that teachers manipulate *signs* and symbols (of various kinds, language, equations, images, video, and so on). Second, this definition emphasizes the importance of teacher agency –the *conscious* manipulation of signs for educative or communicative purposes. Third, teachers are able to *subvert* these signs, implying that the sign-systems are not sacrosanct, but rather are human constructions that teacher can design and re-design for their particular context. Fourth, this definition emphasizes the value of teacher expertise since subversion is not possible unless the teacher knows the rules of the game, and are *fluent* enough to know which rules to bend, which to break, and which to leave alone. Fifth, this definition emphasizes teacher *creativity*. As we know the wicked problems (Rittel & Webber, 1973) of teaching with technology demand creative solutions. Most technological tools we use (Office software, Blogs, etc.) are not designed for teachers, and we have to re-purpose (subvert) them for their needs.

Viewing teachers' use of technology as a new literacy emphasizes the role of the teacher as a producer (as designer), away from the traditional conceptualization of teachers as consumers (users) of technology. When teachers are able to flexibly navigate the landscape of technology, pedagogy, and content, they become responsible for the total curriculum, or the Total PACKage (TPACK).

Example of Creatively Navigating the TPACK Landscape

Supreme Court Justice Potter Stewart once famously called pornography hard to define, "but I know it when I see it." This definition, and the acknowledgement of the difficulty of constructing one, applies to attempts to define creativity. If we are to emphasize creativity, however, we need to develop a better more rigorous articulation of it.

Too often creativity is regarded as being something new, irrespective of use. We argue that mere novelty does make something creative. Novelty needs to be joined to *purpose* – a creative solution, product, or artifact is both novel and useful. Creative solutions often go beyond mere novelty and functionality to include a strong aesthetic quality. Creative products and solutions are deeply bound to the context within which they occur; they are integrated, organic and whole. Thus creative solutions are *novel*, *effective* and *whole*. Taking each of these worlds in turn we get a range of meanings, a constellation of words that illuminate what a creative solution is:

- Novel — Fresh, unusual, unique, surprising, startling, astonishing, astounding, germinal, trendsetting, radical, revolutionary, influential, pioneering
- Effective — Valuable, important, significant, essential, necessary, logical, sensible, relevant, appropriate, adequate, functional, operable, useful, user-friendly
- Whole — Organic, ordered, arranged, organized, formed, complete, elegant, graceful, charming, attractive, refined, complex, intricate, ornate, interesting, understandable, meaningful, clear, self-explanatory, well crafted, skillful, well made, meticulous

We can then apply this lens to one example of a creative solution developed by a teacher to help her 3rd grade students understand maps (Koehler & Dirkin, 2005). This example was collected as part of a Preparing Tomorrow's Teachers to Use Technology Grant, in which we collected examples of teachers describing their best practices of using technology[4]. The teacher describes, first, her understanding of typical student knowledge about maps at that age, and the difficulties they have in understanding 2d-representations of space, conventions of maps, and taking perspectives such as "bird's eye view" (See figure 4). She reasons that part of the problem that these maps and representational norms are not personal to students, and seem disconnected from their experience and conceptual understanding.

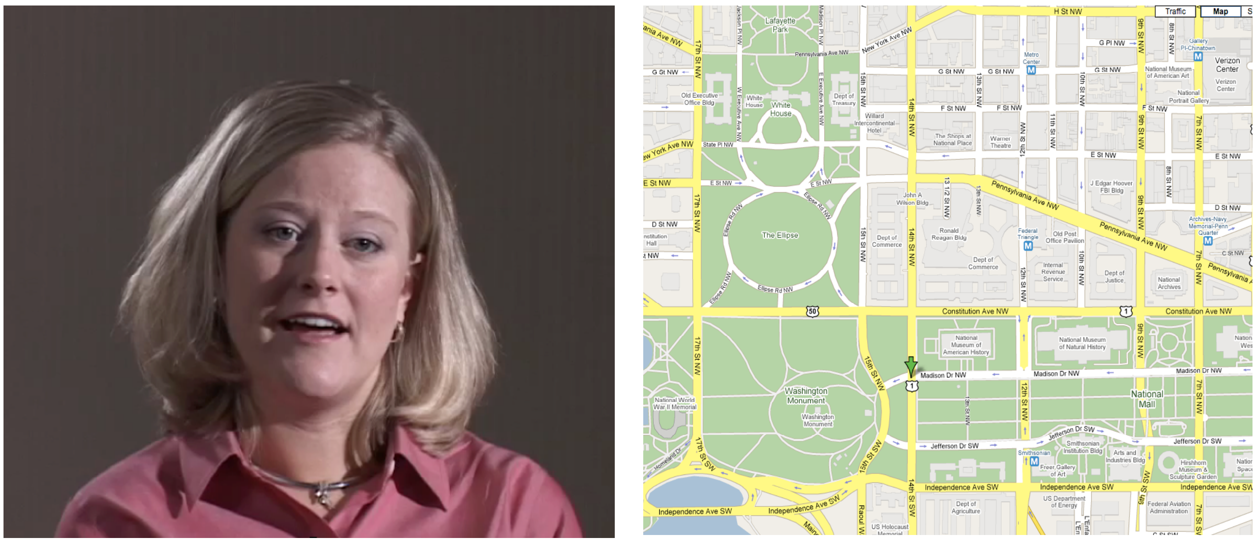

Figure 4: A 3rd Grade Teacher Using Available Technology to Develop Understanding

She crafts a number of activities for students to help them develop understanding. For example, in order to make maps more personal to students, she has them start with a map generated by typing in their own address into mapquest or google maps. She has them copy the map image, work within kidpix to annotate the map with symbols that indicate key landmarks in their neighborhood (places each child is familiar with). This helps students map their understanding of their experiences in their neighborhood to the conventional representations offered by maps. She then works with students to generate directions, use the compass rose, and connect their experiences to their representations. Another activity she does with the students is to film her own tours that she takes when she travels. For example, when on a bus tour of downtown Washington, DC., she used a video camera to film the tour. When she returned to class, she had students work to annotate a map with her route and key landmarks, in order to connect the video to map. That is, they made a "virtual tour".

In crafting these activities, this teacher demonstrates her ability to creatively navigate the TPACK landscape. Not only does she understand the content area deeply, she clearly has knowledge of the other components of TPACK, including knowledge of student understanding and trajectories, the affordances of technology for pedagogy, and how technology impacts

[4] See more examples at: http://ott.educ.msu.edu/pt3video/

content representations. It is this deep understanding that allows her to create a number of *novel* solutions. Each of the connected activities she develops uses existing technology in novel ways. For example, she creatively repurposes technologies, such as mapquest and kidpix, to fufill pedagogical purposes. These uses were not prescribed in any existing curriculum; she developed these uses based on her understanding of students' and their development. Her solutions are highly *effective* as well. Students enter her classroom not understanding maps very well. They leave understanding maps better, and have linked these specialized forms of representation to their own experiences of moving around in the world. And in conclusion, her solutions are *whole*. Her activities flow into one another in way that makes their culmination ordered, elegant, meaningful, and well-crafted.

Conclusion

In this paper we have argued that disciplines are lenses that allow us to look at the world in systematic ways. We would like to end with an example of how the disciplines themselves are evolving and changing, and thus push teachers towards experimenting with newer pedagogical techniques.

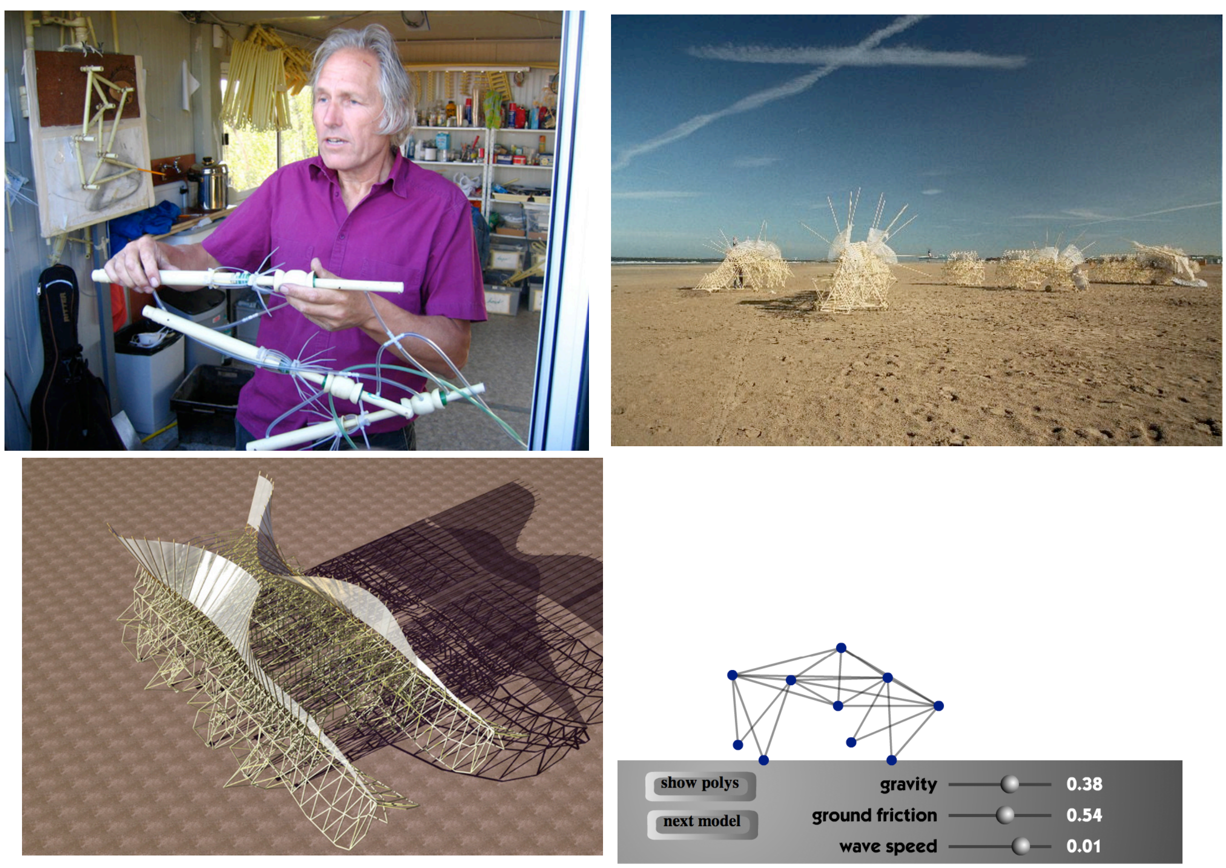

Figure 5: Exploring Cross Disciplinary Boundaries with Theo Jansen's Sand Creatures

Theo Jansen[5] is a designer and artist who explores the idea of motion by creating "Sand Creatures." These creatures are built out of light-weight materials, and are often 6-10 feet tall. They "live" on a sandy beach and move around, on padded feet, through just the force of the wind. As Theo Jensen says, "the boundaries between art and engineering exist only in our minds." What is interesting is that another independent project (SodaPlay.com) came up with a similar idea, but on the computer screen. Users (designers, artists, and possibly students) can construct their own "creatures" that respond to gravity, oscillations (a virtual breeze), and move around.

Educators might wonder what "problem" these technological creatures are supposed to solve. If we seek to look to the standard disciplines for the answers, we may come up short. We need to go beyond techniques and strategies, that may have served us well in the past (though that is debatable), to embrace new possibilities, new ways of looking and being in the world. Teachers have a critical role to play in this new world, but will be able to do so only if they see themselves as being responsible for the Total PACKage, a package that lies at the intersection of Technology, Pedagogy & Content, where the whole is greater than the sum of its parts.

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[5] Learn more about the inspiring work of Theo Jansen at: http://www.strandbeest.com/.

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